Chapter 4
METHODS FOR DEVELOPING MINIMUM FLOW CRITERIA

INTRODUCTION

The District has investigated resources and issues in the St. Lucie Estuary since 1973. The St. Lucie Estuary plays a pivotal role in the operation of the C&SF Project. This estuary is the receiving body for discharges from three canals of the primary water control system in South Florida and provides the eastern connection between the Intracoastal Waterway and the Okeechobee Waterway. In addition, the St. Lucie Estuary is one of two receiving bodies for most of the excess water that must be periodically discharged from Lake Okeechobee. The need for the District and USACE to study this system has been primarily driven by efforts to document the effects of water releases from major canals; provide better methods for release of excess water from Lake Okeechobee; stabilize the St. Lucie (C-44) Canal banks to prevent sloughing and subsequent dumping of sediments to the estuary; and better manage C&SF Project facilities to protect the resources of the St. Lucie Estuary and adjacent waters.

Examples of prior studies by the USACE to determine the effects of discharges from the St. Lucie Canal on the estuary include the following:

- Biological studies of resources in the estuary (Philips and Ingle, 1960; Philips, 1961)
- Studies of the effects of discharges from the canals on these resources (Murdock, 1954; Gunter and Hall, 1963)
- Studies of erosion of the St. Lucie Canal and associated sediment problems in the estuary (USACE 1976, 1994; Williams et al., 1986)

In addition, studies by the District have been conducted for more than 25 years to determine the following:

- Controlled experiments to measure the impacts of high volume releases of water on the estuary (Haunert and Startzman, 1980, 1985)
- An inventory of species and habitats (Woodward-Clyde, 1998, 1999)
- Assessment of bathymetry, sediments, water quality, and nutrient loading in the estuary (Morris, 1986; Haunert, 1988; Chamberlain and Hayward, 1996; Dixon et al., 1994; Schropp et al., 1994)
- Studies of relationships between hydrologic conditions and productivity (Doering,1996; Estevez et al., 1991)

- Literature surveys and mathematical modeling to determine historical watershed characteristics, runoff and salinity conditions in the estuary (see Van Zee in **Appendix D** and McVoy in **Appendix E**)
- Mathematical modeling to determine effects of present and future freshwater flow regimes on the estuary (Morris, 1987; Hu in **Appendix H**; Lin in **Appendix C**; and Qiu in **Appendix F**)

Recently, efforts have shifted toward the need to determine MFL requirements for this system to protect the estuary from significant harm. To initiate this effort, the District contracted with a consultant to conduct a literature review and examine methods being used elsewhere in Florida and nationwide to determine the best strategy for MFL development (Estevez, 2000). This review had several objectives:

- Suggest living resources that can be used as targets, indicators, or criteria for minimum flow determinations in river-dominated estuaries
- Determine how the selection of living resource targets may be affected if working in rivers with long histories of extreme structural and hydrologic alteration
- Summarize lessons learned by other Florida water management districts, other states, and other countries
- Provide an independent expert recommendation of approaches to develop flow management criteria, so as to improve water quality, increase habitat for key organisms, and sustain biodiversity

This effort resulted in specific analyses and recommendations concerning the development of MFLs for the St. Lucie Estuary, including a summary of the relevant goals and objectives, assessment of current knowledge concerning this system, assessment of resources that could provide a basis for establishing quantitative relationships between flows and impacts, and recommended technical approaches. This information was assessed by District staff and was then combined with new information, based on the approaches suggested in this review, to develop technical relationships for MFLs.

Management Goals

Several accounts made by or for the District portray ecological changes to the system during the previous century (Estavez, 2000). Chief among these changes were sedimentation, sediment contamination, altered seasonal flows, highly varying salinities, loss of submerged aquatic vegetation, changes in distribution and composition of oyster reefs, hypoxia and anoxia, phytoplankton blooms, low transparency, and declines in the abundance of valued fish and invertebrate species.

Taken as a whole, these changes may be understood as the consequence of two opposing trends that affect the St. Lucie Estuary. On the one hand, this estuary is becoming more saline during dry periods because an inlet was opened, channels were dug, sea level continues to rise, and local aquifers are salinized or depleted. On the other hand, this system receives more fresh water during wet periods because flood control canals were constructed, the estuary was connected to Lake Okeechobee, and runoff from farmland and impervious urban developments is increasing.

The District seeks to improve the management of freshwater inflow to the estuary. The minimum flow program will be used to define low flow regimes that cause significant harm. Efforts such as the CERP and the associated Indian River Lagoon Feasibility Study (USACE and SFWMD, 2001) provide means to manage high flow events and restore some of the system's lost hydrologic and ecological functions. To guide these efforts, the District has employed three sets of provisional or working goals for the estuary:

- **Set 1** - "Make the benthic environment continuously inhabitable by epifauna and infauna, in densities and diversities that exceed those typical of pollution-indicator communities," and also "make bottom and water conditions able to support some amount of submerged aquatic vegetation, where it presently does not occur in the estuary" (Estevez et al., 1991)
- **Set 2** - "Improve and maintain the health of the St. Lucie Estuary ecosystem (by) promoting and sustaining a healthy oyster population; freshwater, brackish, and marine submersed vegetation; juvenile marine fish and shellfish, and successful recreational and commercial fisheries" (Dixon et al., 1994)
- **Set 3** - "Protect, enhance, and rehabilitate estuarine ecosystems" (SFWMD, 1998b) by "improving water quality, increasing available habitat for key organisms, and sustaining biodiversity" (SFWMD, 1999)

Management Objectives

Based on this analysis, consideration of the impacts of hydrologic alterations that have occurred to the system, and assessment of existing resources (see below), hydrologic management objectives for the St. Lucie Estuary should address the following concerns:

- Reduce high level discharges that have severely impacted the central estuary and adjacent coastal waters by causing rapid and extreme fluctuations in salinity and deposition of large amounts of sand and organic sediments
- Improve water quality by limiting the amount of nutrients and pollutants that enter the estuary
- Protect and enhance hydrologic conditions in the remaining natural river systems and watersheds, especially the remaining North and South Fork systems
- Ensure maintenance of a persistent, but not necessarily extensive, oligohaline zone habitat

Development of MFL criteria provides one of many tools that are needed to address these goals and objectives. These criteria will specifically help maintain oligohaline areas, which will, in turn, help protect and enhance natural systems.

ESTABLISHING HYDROLOGIC MANAGEMENT CRITERIA

Conceptual Basis for Minimum Flows

River management is a complex process that requires consideration of a number of variables. Minimum flows are an important component of riverine flow characteristics. However, providing a minimum flow represents only one aspect of management and/or restoration of river hydrology. Focus on a single aspect of river hydrology (minimum flows) is an overly simplistic treatment of complex ecosystem interactions. Long-term hydrological data, especially measures of variability, have been under utilized in most management decisions aimed at river ecosystem protection or restoration (National Research Council, 1992).

Because of the intrinsic ecological complexity of estuaries, scientists and managers have also objected to the idea that minimum flows can be set for estuaries. Complexity in itself is not a sufficient reason to question the concept of minimum flows for estuaries. In fact, it simply supports the fact that complex biological systems, such as those in estuaries, require more study. Due to the lack of understanding and a shortage of previous attempts to establish minimum flows, estuarine scientists and managers do not have even simplistic minimum flow examples to study or criticize. Rather than waiting until all information is available before making a management decision, the best approach is adaptive: set inflows based on assumptions derived from conceptual and mathematical modeling using best available information, monitor the results for success or failure, continue research, and reevaluate flow targets.

Recent Advances in Flow Analysis

Restoring Natural Flow Regimes

Because modifications of hydrologic regimes in rivers are known to directly and indirectly alter the composition, structure, or function of riverine aquatic and wetland ecosystems, most river scientists tend to agree that it is better to approximate natural flow regimes and maintain entire ensembles of species, than to optimize water regimes for one or a few species. In reality, however, the great majority of in stream determinations have been based on one or a few species' requirements. It is now understood that native aquatic biodiversity depends on maintaining or creating some approximation of natural flow variability, and that native species and communities will perish if the environment is pushed outside the range of natural variability. Where rivers are concerned, a natural flow paradigm is gaining acceptance. It states “the full range of natural intra- and interannual variation of hydrologic regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems" (Richter et al., 1997). A corollary idea is that ensembles of species and ensembles of habitats should be used to gage the effect of hydrological alteration. Sentiment for a similar paradigm for estuaries is growing. In river-dominated estuaries, it seems reasonable to evaluate both flows and salinities with respect to their multiple forms of variation.

Richter "Range of Variability" Criteria

A new and robust method was developed for determining hydrologic alterations in rivers (Richter et al., 1996). The "range of variability approach" is based on the calculation of means and coefficients of variability of 32 hydrologic variables grouped into five sets:

- Magnitude of monthly water conditions
- Magnitude and duration of annual extreme conditions
- Timing of annual extreme water conditions
- Frequency and duration of high and low pulses
- Rate and frequency of water condition changes

Comparisons are made between "before" and "after" modifications. In the absence of "before" data, models can be used to estimate water conditions. Some alterations affect only a few indicators, whereas others affect many. Patterns of alteration help managers determine the aspects of flow to modify.

This technique employs more variables and offers more promise in protecting ecosystem integrity. It is gaining in popularity and has been used extensively by the Northwest Florida Water Management District in its role in the Apalachicola-Chatahoochee-Flint Tri-State Compact (USACE, 1998). In cases where restoration is sought for a system with no "natural" flow data, it is necessary to employ hydrologic simulation models to estimate historical conditions. While such models may provide good estimates of impact magnitude, they do not illuminate their causes. Nevertheless, the method captures a number of features, especially rates of change, that are not commonly used in estuarine science and management, but may have important effects on estuarine ecosystems.

The "range of variability approach" can be applied, even when flow data are scant, to set initial river management targets for rivers in which the flow regime has been greatly altered by human developments such as dams and large diversions. If adequate stream flow records exist for at least 20 years of natural conditions, the method can be used directly. In the absence of all 20 years of data, missing data can be estimated. In the absence of any data, models may be employed or normalized estimates can be generated from nearby, similar streams. Some hydrologic variables cannot be generated by these latter methods, affecting the power of the technique.

The criteria for streams pose great difficulty for estuarine managers where tributary data are sparse; where tributaries have been extensively altered for long periods of time; or where regulated flows are only part of an estuary's total freshwater budget.

SYNTHESIS AND APPLICATION

Methods Considered for Use in the St. Lucie Estuary

Several general methods were identified that could be used to establish minimum flows for the St. Lucie River and Estuary. Components of five possible approaches are integrated in this study. These methods are described in general terms below, followed by assessments of their applicability.

1. In Stream Flow Methods. Historical flow, hydraulic, or habitat methods can be used to determine acceptable flows of individual tributaries to rivers. This approach presumes that an estuary's needs for fresh water can be met by providing sufficient water to the streams that flow into it. The approach requires that the majority of estuarine inflow be via streams or other gaged surface waters and that data are available or can be obtained.

2. Hydrological Variability Techniques. Following Richter et al. (1996) this approach extends the in stream techniques through a fuller analysis of flow characteristics. An untested but feasible application of the method would be its use with salinity data rather than flow data. Data requirements are large, but most types of salinity data could be generated through the use of models. Results of natural or historical conditions would be compared to existing or predicted conditions of salinity.

3. Habitat Approaches. Browder and Moore (1981) proposed the concept of analyzing the overlap of dynamic and stationary habitat elements for particular species. This approach could be developed more fully. If submerged aquatic vegetation was targeted, for example, the method would query the probability that appropriate depths, sediment types, salinities, and conditions of water clarity coincided under differing flow regimes.

4. Indicator Species. This approach relates a change in abundance, distribution, or condition of particular species to a flow or salinity. Criteria for selection may include a species' commercial, recreational, or aesthetic value; ecological importance; status as a species at risk (threatened, endangered, etc.), or endemism. Statistical methods attempt to match abundance values to appropriately time lagged inflow or salinity conditions.

5. Valued Ecosystems Component Approaches. An extension of the indicator species approach, valued ecosystem component (VEC) analysis also uses statistical methods, but accounts for more known or suspected intermediate variables. Recommended by the United States Environmental Protection Agency (1987) for national estuary programs to characterize constraints to living resources, VEC analysis plays an important part in a general model for the design of eutrophication monitoring programs in

South Florida estuaries. VEC is a goal driven approach that has the ability to focus research and provide managers with short-term alternatives in data poor estuaries.

Assessment of These Methods Relative to the St. Lucie Estuary

In stream flow methods have limited applicability in the St. Lucie Estuary because of physical changes wrought to natural tributaries and the overwhelming influence of canals. Prospects of using hydrological variability techniques also are poor, for the same reason. In order for this method to work, it would be necessary to employ a natural systems model of the St. Lucie watershed and compare the five Richter classes of hydrologic variability to present day conditions. Such hind cast models may not be reliable sources of data for every Richter comparison. Attempts to compare salinities computed from a natural systems model suffer even larger challenges. Although this modeling approach may not provide all of the information needed to manage water flows to the estuary, District staff felt that it could be used successfully to examine one aspect of flow, namely the MFL criteria.

Habitat approaches offer some promise in the St. Lucie Estuary. The District already is working with shoal grass (*Halodule wrightii*) and American oyster (*Crassostrea virginica)* in this regard. Based on a literature review (Woodward-Clyde, 1998), other St. Lucie Estuary species such as widgeon grass (*Ruppia maritima*) and tape grass (*Vallisneria americana*) merit consideration as part of an oligohaline submerged aquatic vegetation community. Although both of these species occur in the St. Lucie system, they are not widespread or persistent, probably due to rapid changes in salinity. District staff determined that although such approaches may be feasible in the future, not enough information is currently available concerning distribution, life histories, and salinity tolerance to establish quantitative relationships between low rates of freshwater flow and impacts on populations of these organisms in the St. Lucie Estuary.

Since a dominant issue within the St. Lucie Estuary is the prolonged duration and spatial expansion of oligohaline waters, a general "oligohaline habitat" merits formal spatial analysis. In light of District goals, the St. Lucie Estuary should possess a permanent low salinity reach, but not an extensive, persistent one. The difficulty of working with habitats that presently are rare or absent is acknowledged. In the St. Lucie Estuary, for example, it may be necessary to plant submerged aquatic vegetation or clutch for oysters to overcome historical recruitment bottlenecks, and then study their responses to managed flows and salinities. Flows could be varied experimentally, or adopted flows could be monitored through time so as to allow periodic assessments of progress and adjustments to flow.

Indicator species can be suggested in addition to submerged aquatic vegetation and oysters, using as guidance the size and value of existing literature for each and their previous successful use in other estuarine inflow studies. Sedentary species such as *Mercenaria*, *Mulinia*, *Corbicula*, or *Rangia* clams, migratory organisms such as blue crabs *(Callinectes sapidus*) and planktonic fish eggs and larvae have been suggested. The advantages of each include their relative ease of capture and estimation of abundance by fishery-independent methods, and the ability to analyze results against salinity and inflow by calculating their respective salinities of maximum abundance (Peebles et al.,1991). The main disadvantage of their use is the time required to collect adequate time series data, because statistical methods attempt to match abundance values to appropriately time lagged inflow or salinity conditions. Insufficient data are presently available to support the use of indicator species as a basis to establish MFL criteria.

Species identified under habitat approaches or indicator species may be taken as VECs. By the VEC method, empirical goals would be stated for the status of each. Causal links would be identified from the status of each species back through proximate and ultimate controlling factors. In a series of St. Lucie Estuary reports for the District (Estevez et al. 1991; Dixon and Hayward, 1995; Dixon et al. 1994; Hayward and Chamberlain, 1993), Mote Marine Laboratory developed and applied a model methodology incorporating VEC analysis.

Proposed Valued Ecosystem Component for the St. Lucie Estuary

The SFWMD Coastal Ecosystem Department's research program supports application of the resource-based management strategy defined as the VEC approach. This evaluation methodology is similar to a program developed as part of the National Estuary Program (USEPA, 1987). For the purposes of this study, the VEC approach is based on the concept that management goals for the St. Lucie River and Estuary can best be achieved by providing suitable environmental conditions that will support certain key species, or key groups of species, that inhabit this system.

A VEC can be defined as a species, community, or set of environmental conditions and associated biological communities that is considered to be critical for maintaining the integrity of this estuarine ecosystem. District staff propose that the oligohaline zone in the St. Lucie River and Estuary be used as a VEC for purposes of establishing minimum flow conditions for the North Fork of the St. Lucie River. Loss or reduction of this resource below a critical level is considered to constitute significant harm.

Potential VEC species within the St. Lucie Estuary

Potential VEC species within the St. Lucie Estuary may include oysters, submerged aquatic vegetation, juvenile marine fish and shellfish as well as commercially and recreationally important fish. The following analysis of the potential to use these organisms as VECs is extracted from the publication by Dixon and Hayward (1995).

Although there may be oysters in the St. Lucie Estuary, specific recent occurrences have not been reported. Benthic surveys in the St. Lucie Estuary have not listed oysters among the organisms identified (Graves and Strom, 1992; Haunert and Startzman, 1980; 1985). There are historical accounts of oyster reefs in the estuary near Stuart (Gunter and Hall, 1963) and of a commercial oyster fishery in Stuart in 1896 (Wilcox, 1896), but landings of the commercial fishery do not include specific harvesting locations. The management plan for the aquatic preserve in the North Fork lists some potential oyster habitat as an ecological feature of the area (Gardner, 1984).

Beds of submerged aquatic vegetation have been reported in the North Fork of the St. Lucie Estuary and along shorelines in the middle estuary. Historical accounts of submerged aquatic vegetation in the St. Lucie Estuary focus on areas of the estuary adjacent to the Indian River system (Gilmore et al., 1983; Phillips, 1961; Virnstein and Campbell, 1987; Young, 1975; Young and Young, 1977; Young et al., 1974). Phillips (1961) reported *Halodule* in the St. Lucie Estuary until freshwater releases removed the species. Historical references to submerged aquatic vegetation often do not include species identifications. The North Fork Aquatic Preserve Management Plan lists *Ruppia maritima* as the only documented species of sea grass in that area (Gardner, 1984).

Little quantitative information exists regarding the responses of submerged aquatic vegetation and oysters to rapid hydrological changes. Most take the form of static salinity ranges and variations where species are found most often, or of anecdotal reports of mortality following a particular drought or storm, with attendant extreme salinity dislocations. Optimum salinities for oysters depend not only on their requirements, but also on salinity tolerances of predators and phytoplankton food stocks. Little information also exists on the frequency and magnitude of acute salinity fluctuations that can be tolerated by the various submerged aquatic vegetation or oysters, although some species-specific guidelines for mean salinities and variations are summarized in Estevez and Marshall (1993). Much work is necessary to identify the dynamic salinity requirements of submerged aquatic vegetation and the effects of salinity stress on flowering, reproduction, and competition.

Historical data on juvenile marine fish and shellfish, as well as commercially and recreationally important fish, exist (Bureau of Sport Fisheries and Wildlife, 1959; Evermann and Bean, 1896; Gilmore, 1977; Gunter and Hall, 1963; Murdock, 1954; USACE, 1956; Van Os et al., 1981; Wilcox, 1896; Young, 1975; Young et al., 1974). Older historical data, although useful in providing a picture of the estuary as it existed, are of little use in range depictions or mapping efforts, due to a general lack of reference to areas sampled. Again historical species occurrences should be presented in context of the physical configuration of the estuary at the time.

Reasonably current data on juvenile and adult fish and shellfish are available (Haunert and Startzman, 1980; 1985). Samples of biota were collected during selected controlled releases of fresh water to identify hydrologic impacts on fisheries in the St. Lucie Estuary. Data from longer-term studies, generally biannual surveys which are conducted by SFWMD, are currently unreduced but could be used to develop seasonal and additional hydrological dependence of species distributions within the St. Lucie Estuary. These data should be reduced and examined together with flows, estuary physical configuration during the sampling, and literature values on environmental requirements of various life stages. Following the analysis, it may be desirable to sample additional selected seasons or discharges using similar methodologies. Environmental requirements of some important fish and shellfish species in the St. Lucie Estuary are summarized in **Table 8**.

Table 8. Environmental Requirements for Some Important St. Lucie Estuary Species[a]

Species	Salinity	Dissolved Oxygen	Substrate/Habitat	Food Items	Food For	Special Requirements
Striped Mullet' *Mugil cephalus*	0-75 ppt	>4 milligram per Liter (mg/l)		Larval and post larval: zooplankton; juvenile: add detritus; adult: eptbenth and benthic micro algae, macrophyte detritus, grazing seagrasses for epiphytes	Fish and birds	Spawn in deeper and cooler waters; larvae use inshore shallows; commercially important
Pink Shrimp *Penaeus duorarum duorarum*	Juvenile: >20 ppt		Sand, shell, and coral; use shallow grass beds in estuary as nurseries	Benthic organisms	Snook, spotted seatrout, and snappers	larval, postlarval, juveniles, and early adults use estuaries; recreationally and commercially important
Brown Shrimp *Penaeus aztecus*	2-40 ppt, but tied to temperature	>3 mg/l	Loose peat; sandy mud	Omnivores; detritus, small invertebrates, or fish, depending on life stages	Carnivorous fish and crustaceans	Commercially and recreationally important
Hard Clam *Mercenaria mercenaria*	12.5-35 ppt	6.8-7.4 mg/l ideal; anoxia - survived for some time	Sand; shelly sand	Currents important in transport of food items; removal of pseudofeces	Mammals, crabs, and fish	Commercially and recreationally important; can close tightly and respire anaerobically when stressed; longer survival time than oysters
King Mackerel *Scomberomorus cavalla* **Spanish Mackerel** *S. maculatus*	32-36 ppt			Menhaden (*Brevoortia sp.);* Anchovy (*Anchoa sp.*)	Tuna, dolphins, bottlenose dolphins, and sharks	Commercially and recreationally important
Spotted Seatrout *Cynoscion nebulosus*	0-37 ppt 20 optimum	>4 m/L	Prefer *Thalassia* and *Halodule* beds next to deep water	Copepods?, crabs; shrimp?, and fish based on size and availability	Fish and birds	Commercially and recreationally important; not migratory; especially vulnerable to abrupt changes in temperature and salinity
Blue Crab *callinectes sapidus*	fresh - 35 ppt; males fresher, females more saline; juveniles 2-21		Shallow salt marsh; small crabs prefer shallow estuary water with soft detritus bottom layer; large crabs prefer deeper estuary water with hard bottom	Omnivorous; cannibalistic	Mammals, fish, and birds	Commercially important
Snook *Centropomus undecimalis*	fresh to seawater		Mangroves	Opportunistic; carnivores; pelagic feeder	Mammals	Recreationally important
Bay Anchovy *Anchoa mitchilli*	0-44 ppt	1.5-11.9 mg/l	Shallow mud to muddy sand; high turbidity preferred	Zooplankton	Fish and sea birds	Not Commercially and recreationally important; important as a forage fish
American Oyster *Crassostrea virginica*	5-32 ppt; brackish water; 20 ppt provides refuge from marine predators	>l mg/l; anoxia -survived for brief periods	Shell, rocky, or thick mud bottoms preferred; soft mud not good	Currents important in transport of food items and removal of pseudofeces	Mammals, crabs, and fish	Commercially important; able to respire anaerobically for short periods; able to survive brief anoxic periods

a. Source - Dixon and Hayward, 1995

Selection of Species for Enhancement, Protection, and Management

Species selected for management should be drawn from native, noninvasive organisms that occur along a normal regional estuarine gradient, as exemplified by a suitable system in the region. The environmental requirements for sea grasses are less well known than for fish and shellfish and selecting a single species of submerged aquatic vegetation for protection and enhancement is a difficult task. Specific information on submerged aquatic vegetation coverage in the St. Lucie Estuary is lacking, but given the apparent general lack of submerged aquatic vegetation, a more appropriate approach would be to monitor management success based on the appearance of any species of submerged aquatic vegetation. Periodic surveys (annual and biannual) would assess coverage and condition of the beds.

Information on the commercial value and historical landings of various species is available in the literature (Wilcox, 1896) and more recently through trip tickets instituted under National Marine Fishery programs. Recreational value of various species is more difficult to establish, but a creel census (Van Os et al., 1981) in the early 1980s could be used to rank “recreationally desirable” species. Experience of District personnel and local marine extension agents could undoubtedly be used to summarize user groups (i.e., concerned citizens and commercial and recreational fishermen) input. A preliminary (unranked) list might include *Scomberomorus cavalla* and *S. maculatus* (king and Spanish mackerel), *Cynoscion nebulosus* (trout), *Sciaenops ocellatus* (redfish), *Centropomus undecimalis* (common snook), *Mugil cephalus* (striped mullet), *Megalops atlanticus* (tarpon), and *Trachinotus carolinus* (pompano).

Ecological importance is difficult to define and can emphasize top predators on the assumption that their presence indicates the health of the entire trophic structure, or keystone species on which others depend. Other important species are those that convert phytoplankton to fish biomass, forming the base of the trophic structure. A more representative approach would select several species from various feeding guilds to monitor the interactions of various trophic levels and perhaps trace any change in structure experienced by the estuary over time. Sufficient literature information exists to identify representatives of various trophic levels and to select these species from the species lists indigenous to the St. Lucie Estuary

In actual practice, the sampling and monitoring programs used to evaluate management effects on a single species, whether submerged aquatic vegetation or fisheries, will also effectively and economically gather information on multiple species. These data should be retained and used to evaluate overall success. Progress reports to user groups may choose to emphasize one species over another, but should not represent the entire evaluation process.

Management efforts could aim to provide suitable environmental conditions at areas of appropriate potential habitat for selected species. It should be recognized, however, that water quality goals may be achieved, while seasonal distributions, recruitment patterns, and recovery times may delay the return of the selected VEC.

PROCESS USED TO DEVELOP MFL CRITERIA

Literature Review

Importance of the Oligohaline Zone

Appendix B, a summary of available literature regarding species that occur in the oligohaline zones in estuaries, was prepared to assist in the development of criteria for the St. Lucie Estuary. Key findings based on this appendix are presented below. Based on results of this study, District staff infer that the oligohaline zone in the St. Lucie Estuary must be important because it provides critical habitat for many species that utilize the river, the adjacent Indian River Lagoon, and the offshore reefs.

An estuary is defined as the area where a river meets the ocean. Fresh water from the river carries nutrients and organisms into the estuary where they provide a nutritional basis for a highly productive transitional food chain. The resulting change in salinity conditions produces a stressful environment that, on the one hand, restricts the number of organisms, but on the other hand, provides a highly productive environment for species that are adapted to survive this stress.

The oligohaline zone in an estuary is an area where salinity conditions are low. Although the exact definition may vary among authors, it is generally considered to occur within the range from 0.5- to 5.0-ppt salinity. This zone is important because it supports important physical, chemical, and biological processes that are necessary to maintain the range of ecological, species, and habitat diversity in the region that includes the St. Lucie River system, the Indian River Lagoon, and the adjacent waters of the Atlantic Ocean. The oligohaline zone provides a buffer or interface between fresh and marine waters that provides habitat and a nursery function for juveniles and adults of both estuarine and marine organisms. These organisms include the juveniles and adults of fishes, shrimps, and crabs that support important regional food fisheries and sport fishing. A broader array of other species that provide necessary food sources and habitat, including aquatic vegetation, micro invertebrates, macro invertebrates, and insects also inhabit this zone. A list of representative fish and shellfish species that occur in oligohaline waters in the St. Lucie Estuary is provided in **Table 9**.

Included in the **Table 9** are species identified by Gilmore (1977) as common or abundant estuarine or marine species of the Indian River Lagoon. The Indian River Lagoon is a narrow estuarine lagoon system extending from Ponce de Leon Inlet in Volusia County south to Jupiter Inlet in Palm Beach County. It lies within the zone of overlap between two well known fish faunal regimes (i.e., the warm temperate Carolinian and the tropical Caribbean). A total of 454 fish species were identified in the study and were characterized by regional biotype in addition to relative abundance (rare, occasional, frequent, common, or abundant). For purposes of our investigation only those estuarine, oligohaline species collected in freshwater tributaries and canals and ranging in relative abundance from frequent to abundant were included in this list. The time of year or exact salinities in which these species were captured can not be determined from the publication.

Table 9. A Partial List of Fish and Shellfish Collected in Oligohaline Waters

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference (Full citations included in Appendix B)
Achirus lineatus[a]	Lined sole			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Adinia xenica	Diamond killifish			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Albula vulpes[a]	Bonefish		✔		St. Lucie River, Florida	Haunert and Startzman, 1985
Alosa aestivalis	Blueback herring			✔	North Carolina	Rozas and Hackney, 1984
Alosa alabamae	Alabama shad			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Alosa chysochloris	Skipjack herring			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Alosa pseudoharengus	Alewife		✔		Parker River Estuary, Massachusetts	Hughes et al., 2000
Amia calva	Bowfin			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Anguilla rostrata	American eel			✔	Lake Maurepas, Louisiana Parker River Estuary, Massachusetts	Hastings et al., 1987 Hughes et al., 2000
Anchoa mitchilli[a]	Bay Anchovy	✔	✔		Not specified St. Lucie River, Florida York River, Virginia Barataria Basin, Louisiana St. Louis Bay, Missouri North Carolina Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana. Old Fort Bayou, Missouri Little Manatee River, Florida	Gunter, 1961 Gunter and Hall, 1963 Markle, 1976 Day et al., 1981 Hackney and de la Cruz, 1981 Rozas and Hackney, 1984 Felley, 1987 Hastings et al., 1987 Peterson and Ross, 1991 Edwards, 1992
Apeltes quadracus	Four-spined stickleback			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Aphredoderus sayanus	Pirate perch			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Aplodinotus grunniens	Freshwater drum			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Archosargus probatocephalus[a]	Sheepshead			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Arius felis[a]	Hardhead catfish	✔	✔	✔	Lake Maurepas, Louisiana Little Manatee River, Florida St. Lucie River, Florida	Hastings et al., 1987 Edwards, 1992 Gunter and Hall, 1963
Astroscopus sp.	Stargazer			✔	North Carolina	Rozas and Hackney, 1984
Bagre marinus[a]	Gafftopsail catfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Bairdiella chrysoura[a]	Silver perch			✔	York River, Virginia North Carolina	Markle, 1976 Rozas and Hackney, 1984
Brevoortia patronus	Gulf menhaden		✔		Grand and White Lakes, Louisiana Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana Old Fort Bayou, Missouri	Gunter, 1961 Felley, 1987 Hastings et al., 1987 Peterson and Ross, 1991
Brevoortia smithii[a]	Fine-scale menhaden		✔		St. Lucie River, Florida	Gunter and Hall, 1963
Brevoortia tyrannus[a]	Atlantic menhaden		✔		North Carolina	Rozas and Hackney, 1984

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table 9. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference (Full citations included in Appendix B)
Callenectes sapidus[a]	Blue crab	✔	✔		Grand and White Lakes, Louisiana Barataria Basin, Louisiana St. Louis Bay, Missouri	Gunter, 1961 Day et al., 1981 Hackney and de la Cruz, 1981
Caranx hippos[a]	Crevalle jack			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Carpoides carpio	River carpsucker			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Catostomus commersoni	White sucker		✔		Parker River Estuary, Massachusetts	Hughes et al., 2000
Centropomus undecimalis[a]	Snook		✔		St. Lucie River, Florida Indian River Lagoon, Florida Little Manatee River, Florida	Gunter and Hall, 1963 Haunert and Startzman, 1980, 1985 Peterson and Gilmore, 1991 Edwards, 1992
Citharichthys spilopterus[a]	Bay whiff			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Crangon septemspinosa	Sand shrimp			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Cynoscion arenarius	Sand seatrout			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Cynoscion nebulosus[a]	Spotted seatrout		✔	✔	St. Louis Bay, Missouri Little Manatee River, Florida	Hackney and de la Cruz, 1981 Edwards, 1992
Cynoscion regalis[a]	Weakfish			✔	York River, Virginia	Markle, 1976
Cyprinodon variegatus[a]	Sheepshead minnow			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Cyprinus carpio	Common carp			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Dasyatis sabina[a]	Atlantic stingray			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Diapterus olisthostomus[a]	Sand perch			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Diapterus plumieri[a]	Striped mojarraC			✔	Little Manatee River, Florida	Edwards, 1992
Dormitor maculatus	Fat St. Lucie Estuaryeper			✔	North Carolina	Rozas and Hackney, 1984
Dorosoma cepedianum[a]	Gizzard shad			✔	North Carolina St. Lucie River, Florida Lake Maurepas, Louisiana	Rozas and Hackney, 1984; Haunert and Startzman, 1985 Hastings et al., 1987
Dorosoma petenense[a]	Threadfin shad			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Elassoma zonatum	Banded pygmy sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Eleotris pisonis	Spinycheek St. Lucie Estuaryeper			✔	North Carolina	Rozas and Hackney, 1984
Elops saurus[a]	Ladyfish		✔	✔	James River, Virginia St. Lucie River, Florida Lake Maurepas, Louisiana	Govoni and Merriner, 1978; Haunert and Startzman, 1985 Hastings et al., 1987
Enneacanthus gloriosus[a]	Bluespotted sunfish			✔	Atlantic coast	Rozas and Hackney, 1983 citing Raney and Massmann, 1953

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table 9. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference (Full citations included in Appendix B)
Esox niger	Chain pickerel			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Euciniostomus juveniles[a]	Mojarra		✔		Little Manatee River, Florida	Edwards, 1992
Eucinostomus argenteus[a]	Spotfin Mojarra			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Eucinostomus lefroyi	Mottled mojarra			✔	North Carolina	Rozas and Hackney, 1984
Evorthodus lyricus[a]	Lyre goby			✔	St. Louis Bay, Missouri North Carolina	Hackney and de la Cruz, 1981 Rozas and Hackney, 1984
Fundulus chrysotus	Golden topminnow			✔	Gulf Coast Lake Maurepas, Louisiana	Hastings et al., 1987
Fundulus confluentus[a]	Marsh killifish			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Fundulus diaphanus	Banded killifish			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Fundulus grandis[a]	Gulf killifish			✔	St. Louis Bay, Missouri Lake Maurepas, Louisiana	Hackney and de la Cruz, 1981 Hastings et al., 1987
Fundulus heteroclitus	Mummichog			✔	North Carolina Plum Island Sound, Massachusetts Parker River Estuary, Massachusetts.	Rozas and Hackney, 1984 Deegan and Garritt, 1997 Hughes et al., 2000
Fundulus jenkinsi	Saltmarsh topminnow			✔	Old Fort Bayou, Missouri	Peterson and Ross, 1991
Fundulus luciae	Spotfin killifish			✔	North Carolina	Rozas and Hackney, 1984
Fundulus pulvereus	Bayou killifish			✔	Lake Maurepas, Louisiana Old Fort Bayou, Missouri	Hastings et al., 1987 Peterson and Ross, 1991
Fundulus seminolis[a]	Seminole killifish			✔	Little Manatee River, Florida	Edwards, 1992
Gambusia affinis[a]	Mosquitofish	✔	✔		St. Lucie River, Florida North Carolina St. Lucie River, Florida Lake Maurepas, Louisiana Little Manatee River, Florida	Gunter and Hall, 1963 Rozas and Hackney, 1984 Haunert and Startzman, 1985 Hastings et al., 1987 Edwards, 1992
Gobionellus boleosoma[a]	Darter goby			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Gobionellus hastatus[a]	Sharptail goby			✔	North Carolina	Rozas and Hackney, 1984
Gobionellus shufeldti	Freshwater goby			✔	North Carolina Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Hastings et al., 1987
Gobiosoma bosc[a]	Naked goby			✔	St. Louis Bay, Missouri Lake Maurepas, Louisiana	Hackney and de la Cruz, 1981 Hastings et al., 1987
Heterandria formosa[a]	Least killifish			✔	St. Lucie River, Florida Lake Maurepas, Louisiana	Gunter and Hall, 1963; Hastings et al., 1987
Ictalurus catus[a]	White catfish	✔	✔		St. Lucie River, Florida York River, Virginia North Carolina St. Lucie River, Florida	Gunter and Hall, 1963 Markle, 1976 Rozas and Hackney, 1984 Haunert and Startzman, 1985

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table 9. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference (Full citations included in Appendix B)
Ictalurus furcatus	Blue catfish			✔	Lake Maurepas Louisiana	Hastings et al., 1987
Ictalurus melas	Black bullhead			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Ictalurus natalis	Yellow bullhead			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Ictalurus nebulosus[a]	Brown bullhead			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Ictalurus punctatus[a]	Channel catfish			✔	York River, Virginia Lake Maurepas, Louisiana	Markle, 1976 Hastings et al., 1987
Ictiobus bubalus	Smallmouth buffalo			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Labidesthes sicculus	Brook silverside			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lagondon rhomboides[a]	Pinfish			✔	North Carolina Little Manatee River, Florida	Rozas and Hackney, 1984 Edwards, 1992
Leiostomus xanthurus[a]	Spot			✔	York River, Virginia North Carolina Lake Maurepas, Louisiana Little Manatee River, Florida	Markle, 1976 Rozas and Hackney, 1984 Hastings et al., 1987 Edwards, 1992
Lepisosteus oculatus	Spotted gar			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepisosteus ossesus	Longnose gar			✔	North Carolina Hastings et al., 1987	Rozas and Hackney, 1984; Hastings et al., 1987
Lepisosteus spatula	Alligator Gar			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis gibbosus	Pumpkinseed	✔	✔		North Carolina	Rozas and Hackney, 1984
Lepomis gulosus	Warmouth			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis macrochirus[a]	Bluegill	✔	✔		St. Louis Bay, Missouri Lake Maurepas, Louisiana Little Manatee River, Florida Plum Island Sound, Massachusetts.	Hackney and de la Cruz, 1981 Hastings et al., 1987 Edwards, 1992 Deegan and Garritt, 1997
Lepomis meglaotis	Longear sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis microlophus[a]	Redear sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis punctatus	Spotted sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lepomis symmetricus	Bantam sunfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Lucania parva[a]	Rainwater killifish			✔	St. Louis Bay, Missouri Lake Maurepas, Louisiana Little Manatee River, Florida	Hackney and de la Cruz, 1981 Hastings et al., 1987 Edwards, 1992
Lutjanus griseus[a]	Gray snapper			✔	St. Lucie River, Florida	Gunter and Hall, 1963
Megalops atlanticus[a]	Tarpon		✔		St. Lucie River, Florida	Haunert and Startzman, 1985
Membras martinica[a]	Rough silverside			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Menidia beryllina[a]	Inland or tidewater silverside			✔	North Carolina Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana Old Fort Bayou, Missouri Little Manatee River, Florida	Rozas and Hackney, 1984 Felley, 1987 Hastings et al., 1987 Peterson and Ross, 1991 Edwards, 1992

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table 9. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference (Full citations included in Appendix B)
Menidia menidia[a]	Atlantic silverside			✔	Plum Island Sound, Massachusetts Parker River Estuary, Massachusetts	Deegan and Garritt, 1997 Hughes et al., 2000
Microgobius gulosus[a]	Clown goby			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Micropogonias undulatus[a]	Atlantic croaker		✔	✔	Grand and While Lakes, Louisiana York River, Virginia Upper Barataria Basin, Louisiana North Carolina Lake Maurepas, Louisiana	Gunter, 1961 Markle, 1976 Day et al., 1981 Rozas and Hackney, 1984 Hastings et al., 1987
Micropterus salmoides[a]	Largemouth bass	✔	✔		St. Louis Bay, Missouri North Carolina Lake Maurepas, Louisiana	Hackney and de la Cruz, 1981 Hackney and Rozas, 1984 Hastings et al., 1987
Morone americana	White perch			✔	York River, Virginia Plum Island Sound, Missouri	Markle, 1976 Deegan and Garritt, 1997
Morone chrysops	White bass			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Morone mississippiensis	Yellow bass			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Morone saxatilis	Striped bass	✔	✔	✔	York River, Virginia North Carolina Lake Maurepas, Louisiana	Markle, 1976 Rozas and Hackney, 1984 Hastings et al., 1987
Mugil cephalus[a]	Striped mullet[a]		✔	✔	St. Lucie River, Florida St. Louis Bay, Missouri North Carolina Lake Maurepas, Louisiana Little Manatee River, Florida	Haunert and Starzman, 1980 Hackney and de la Cruz, 1981 Rozas and Hackney, 1984 Hastings et al., 1987 Edwards, 1992
Mugil curema[a]	Silver mullet[a]		✔		St. Lucie River, Florida	Gunter and Hall, 1963
Myrophis punctatus	Speckled worm eel			✔	North Carolina Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Hastings et al., 1987
Notemigonus crysoleucas[a]	Golden shiner			✔	St. Lucie River, Florida Lake Maurepas, Louisiana	Hastings et al., 1987, 2000
Notropis emiliae	Pugnose minnow			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Notropis petersonii	Coastal shiner			✔	Old Fort Bayou, Missouri	Peterson and Ross, 1991
Noturus gyrinus	Tadpole madtom			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Oligoplites saurus[a]	Leatherjacket			✔	St. Louis Bay, Missouri	Hackney and de la Cruz, 1981
Osmerus mordax	Rainbow smelt			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Palaemonetes bulgaris	Grass shrimp			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Palaemonetes pugio	Grass shrimp	✔	✔		St. Louis Bay, Missouri North Carolina	Hackney and de la Cruz, 1981 Rozas and Hackney, 1984
Paralichthys lethostigma	Southern flounder		✔		North Carolina Calcasieu Estuary, Louisiana Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Felley, 1987 Hastings et al., 1987

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

Table 9. A Partial List of Fish and Shellfish Collected in Oligohaline Waters (Continued)

Scientific Name	Common Name	Size Class: Adult	Size Class: Juvenile	Size Class: Not Specified	Location	Reference (Full citations included in Appendix B)
Farfantepenaeus aztecus[a]	Brown shrimp		✔	✔	Grand and White Lakes, Louisiana St. Lucie River, Florida Old Fort Bayou, Missouri	Gunter, 1961 Peterson and Ross, 1991
Farfantepenaeus setiferus	White shrimp		✔	✔	Grand and White Lakes, Louisiana Calcasieu Estuary, Louisiana Old Fort Bayou, Missouri	Gunter, 1961 Gunter and Hall, 1963 Felley, 1987 Peterson and Ross, 1991
Petromyzon marinus	Sea lamprey			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Pleuronectes americanus	Winter Flounder			✔	Plum Island Sound, Missouri	Deegan and Garritt, 1997
Poecilia latipinna[a]	Sailfin molley			✔	Little Manatee River, Florida	Edwards, 1992
Pogonias cromis[a]	Black drum			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Polyodon spathula	Paddlefish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Pomatomus saltatrix[a]	Bluefish			✔	North Carolina Plum Island Sound, Missouri	Rozas and Hackney, 1984 Deegan and Garritt, 1997
Pomoxis annularis	White crappie			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Pomoxis nigromacuatus[a]	Black crappie			✔	North Carolina St. Lucie River, Florida Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Haunert and Startzman, 1985 Hastings et al., 1987
Pungitius pungitius	Nine-spined stickleback			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Pylodictus olivaris	Flathead catfish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Sciaenops ocellatus[a]	Red drum		✔	✔	St. Lucie River, Florida Little Manatee River, Florida	Haunert and Starzman, 1980 Edwards, 1992
Strongylura marina[a]	Atlantic needlefish			✔	North Carolina Lake Maurepas, Louisiana	Rozas and Hackney, 1984 Hastings et al., 1987
Symphurus plagiusa[a]	Blackcheek tonguefish			✔	Gulf and Atlantic Coasts	Rozas and Hackney, 1983 citing Rounsefell, 1964
Syngnathus fuscus	Northern pipefish			✔	Parker River Estuary, Massachusetts	Hughes et al., 2000
Syngnathus louisianae[a]	Chain pipefish			✔	Gulf Coast	Rozas and Hackney, 1983 citing Dahlberg, 1972
Sygnathus scovelli[a]	Gulf pipefish			✔	Lake Maurepas, Louisiana	Hastings et al., 1987
Synodus foetens[a]	Inshore lizardfish			✔	Gulf Coast	Rozas and Hackney, 1983 citing Dahlberg, 1972
Trinectes maculatus[a]	Hogchoker			✔	Grand and White Lakes, Louisiana York River, Virginia Lake Maurepas, Louisiana Little Manatee River, Florida	Gunter, 1961 Markle, 1976 Hastings et al., 1987 Edwards, 1992

a. Species found in the St. Lucie Estuary (Gunter and Hall, 1963; Haunert and Startzman, 1980, 1985)

The District conducted fish surveys (1975-1976 and 1981-1983) using an otter trawl and seine at nineteen locations throughout the St. Lucie Estuary (Haunert and Startzman, 1980; Haunert, 1987). These surveys documented 101 species of which many were found throughout the estuary and did not have a propensity for low salinity habitat in the dry season. However, the surveys also revealed that the juveniles of important forage fish did prefer low salinity habitat during the dry season (**Table 10**). In addition, juvenile redfish *(Sciaenops ocellata)*, an important game fish, was frequently captured only in low salinity waters from October to February.

Table 10. St. Lucie Estuary Juvenile Fish Species that Utilize Low Salinity Habitat during the Dry Season (October to May)[a]

Fish Species	Period of Utilization
Striped mullet (*Mugil cephalus*)	January to May
Bay anchovy (*Anchoa mitchilli*)	November to January
Silver perch (*Bairdiella chrysoura*)	April to May
Croaker (*Micropogonias undulatus*)	October to May
Redfish (*Sciaenops ocellata*)	October to February

a. Source: Haunert and Startzman, 1980

Location of Oligohaline Habitat

In his analysis of previous research studies that could provide a basis to establish flow criteria for the St. Lucie Estuary, Estevez (2000) concluded that the St. Lucie Estuary should possess a permanent, low salinity reach. Although most of the estuary may become oligohaline during high discharge periods, the areas where oligohaline habitat occurred under natural (predrainage) conditions were the upstream reaches of the major tributary streams and rivers. Many of the natural streams, such as Bessey Creek, have been channelized and their watersheds altered by dredging and filling. However, two relatively extensive riverine systems remain within the watershed: the North Fork River and the South Fork River.

Water Quality

In the St. Lucie Estuary, construction of major drainage canals has greatly increased the effective boundaries of the watershed. The canals thus contribute larger amounts of freshwater flow and higher levels of nutrient loading than occurred under historic conditions through the natural streams. Flows from the remaining natural streams and watersheds have been reduced.

Data collected by the SFWMD indicate that high levels of phosphorus and nitrogen loading occur periodically when these canals are discharging and the estuary is receiving excessive amounts of nutrients. The average concentrations of phosphorus and nitrogen observed in the St. Lucie Estuary are in the “poor” to “fair” range when compared to other Florida estuaries (Hand et al., 1990, 2001b; Chamberlain and Hayward, 1996).

Several lines of evidence suggest that sediments provide an additional internal source of nutrients in the St. Lucie Estuary. Nitrogen and phosphorus appear to be internally generated by resuspension of bottom sediments. This resuspension occurs during high wind conditions or when high volumes and rates of inflow occur from the canals and tributaries (Doering, 1996; Chamberlain and Hayward, 1996).

Analyses of ten years of data (SFWMD, 2001b) indicate that conditions throughout the estuary generally seem to be fairly stable. Increases in phosphorus concentrations and ammonia nitrogen may be occurring in both the North and South Forks, resulting in higher concentrations of chlorophyll *a*. Dissolved oxygen concentrations have increased in the South Fork while other areas show no significant trends over time.

Hypoxic and anoxic conditions occur fairly often in the St. Lucie Estuary. In some areas, more than 20 percent of samples are below the state standard for Class II waters of 4.0 milligrams per liter). Anoxic conditions tend to occur more frequently at stations that are located immediately downstream from the major canals than they occur downstream from the natural tributaries (SFWMD, 2001b). Studies by the FDEP indicate that water and sediments in these canals also often contain high concentrations of pesticides and heavy metals (FDEP, 2000c, 2000d; FDEP, 2001a).

Results of the above studies are consistent with the explanation that the various canals and tributaries that flow into the estuary transport fresh water and substantial amounts of nutrients, organic matter, tannins, and suspended solids. This fresh water mixes with increasing amounts of salt water as it is transported out of the estuary, resulting in increased concentrations of chlorophyll, decreased color, and increased turbidity.

Poor water quality conditions are often most apparent in areas where fresh water first interfaces with salt water, as is the case at the confluences of tributaries and canals with the estuary. This mixing zone is characterized by high rates of biological productivity, high levels of turbidity, decreasing color, and high levels of biological oxygen demand. Significant stratification may occur at such interfaces, especially during periods of low flow when less physical mixing occurs. Such stratification has been observed in the St. Lucie Estuary and forms a freshwater "lens" that floats across the surface of denser saline waters. High productivity, high turbidity, and reduced light penetration at the interface can result in low concentrations of dissolved oxygen near the bottom.

Based on these analyses, District staff cannot at this time determine the effects that implementing the proposed MFL criteria will have on water quality in the estuary. Providing additional freshwater flow to the estuary through the North and South Forks will provide additional influx of nutrients during these periods, but will also transport additional sediments and pollutants. Providing low rates of freshwater flow during dry periods may increase stratification and lower dissolved oxygen concentrations. Additional research is needed to define these relationships.

Assessment of Current and Historical Conditions

In order to assess the extent and nature of oligohaline conditions in the St. Lucie River and Estuary, assessments were made of present and past conditions in the system with respect to natural systems, land use, and hydrology. Present day conditions in the St. Lucie River and Estuary watershed were determined for use in the regional water supply plans (SFWMD, 1998a, 2000b). These analyses included assessment of current hydrologic conditions and operation of major canals and structures, recent land use throughout the watershed, and estimates of agricultural, urban, and industrial water use. This information for 1995 was compiled to produce the 1995 Base Case conditions that were analyzed in the regional water supply plans (SFWMD, 1998a; 2000b).

Historical land use/land cover conditions in the watershed were determined based on a review of historical accounts, maps, surveys, and other data collected from this region (**Appendix E**). Conclusions from this study are based on examination of field notes and plat maps for five of approximately 30 townships that comprise the watershed. Plat maps for a number of additional townships were examined briefly. Conclusions from this study include the following:

- Three main physiographic regions appear to have been present in the predrainage watershed: 1) an area of pinelands and seasonal ponds mosaic, 2) an area of prairie and seasonal ponds mosaic, and 3) an area referred to as the Halpatta Swamp, which was later named the Allapattah Flats.
- All three physiographic regions appear to have been very flat, with the elevation difference between pinelands and ponds probably often as little as two feet.
- The prairie mosaic was described primarily in the northern portion of the watershed. The sawgrass marshes and bordering forested wetlands that formed the Halpatta Swamp were present along the western edge of the watershed, along the eastern foot of the high northwest-southeast trending ridge. Cypress occurring in pond-like patches seems to have been confined to the southernmost townships of the watershed.
- Although there appeared to be some interconnection among the ponds in the watershed, generally, there does not appear to be a strong suggestion of extensive connection or extensive surface runoff.
- The watershed may have contributed more water to the St. Lucie River base flow through ground water discharge than through surface runoff. The long duration of standing water in ponds and even longer duration in the sawgrass marshes indicate that the base flow recession that occurred during dry periods was a gradual process.

The presence of extensive surface water throughout the watershed, the limited degree of surface runoff, and the overall similarity in land cover characteristics surrounding the headwaters, suggest that the North and South Forks of the St. Lucie River may have had similar discharges.

Hydrologic and Hydrodynamic Modeling

Since the amount of historical hydrologic data for this system is very limited, the District developed and adapted several mathematical models to provide tools necessary to estimate both historical and present conditions in the estuary. The models were calibrated and verified using available data and applied to estimate past and present conditions in the watershed and estuary.

Historical and current flow conditions throughout the St. Lucie Estuary were analyzed using watershed models to determine how flows vary over time. The watershed models then provided information, in the form of inflows, to an estuarine hydrodynamic/ salinity model to determine the extent and movement of the oligohaline zone (**Figure 13**). This section briefly describes each model and its interaction with other models.

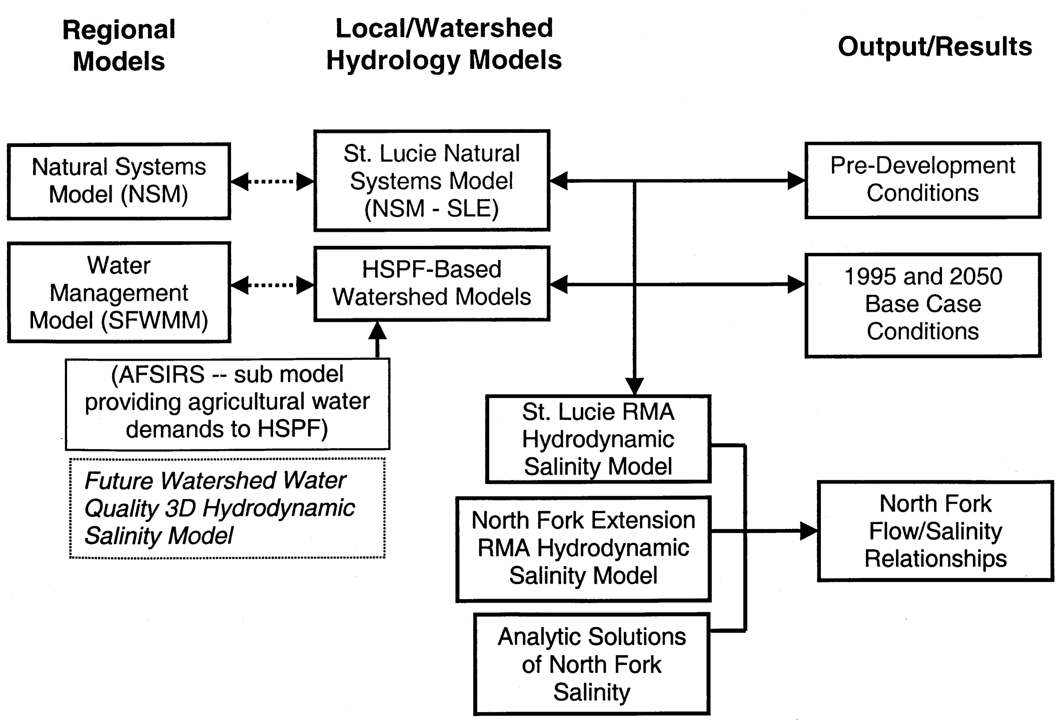

Figure 13. Model Interactions

Natural Systems Model - St. Lucie Estuary

A watershed-scale hydrologic model called the Natural Systems Model – St. Lucie Estuary (NSM - St. Lucie Estuary) defines the flows entering the estuary under undeveloped conditions (**Appendix D**). This model is fully explicit and models all hydrologic processes in the watershed including evapotranspiration, surface water runoff, and ground water flow. The hydrology is modeled continuously for each day over a 31-year simulation period.

The model needs ground surface elevations, soil hydraulic conductivity, and a predevelopment land use map of the area. The land use map is used to assign model parameters (e.g., root depths, crop-specific adjustment factors for evapotranspiration, surface runoff characteristics) to each modeled node.

The model predicts daily runoff over a 31-year simulation period. Attention is focused on flow entering into the North Fork of the St. Lucie River, where the oligohaline habitat is located. Statistical analysis of the NSM - St. Lucie Estuary flow time series was used to define minimum flow conditions.

Hydrologic Systems Program FORTRAN Model

A set of five basin-scale hydrologic models built with a model called the Hydrologic Systems Program FORTRAN[1] (HSPF) defines flows entering the estuary under current land use conditions (**Appendix C**). HSPF documentation appears in **Appendix C**. Like NSM, this model simulates all major flow components at a daily time step over a 31-year period. Unlike NSM, this model does not explicitly model the flow process, but instead relies on calibrated flow regression parameters to estimate surface water and ground water movement.

Data requirements are similar to those of NSM. The model does not explicitly use elevation data, but the model does require flow patterns and calibration of flow to measured data serves a similar function. The HSPF was used to simulate runoff from the five basins that flow into the St. Lucie River.

Resource Management Associates, Inc. (RAM) Model

Resource Management Associates, Inc. (RMA) developed the original code for a hydrodynamic model that can be used to represent water exchange processes in estuaries. This model was modified by the SFWMD for specific application in the St. Lucie Estuary. The RMA hydrodynamic models show how fresh water interacts with tidal forces within the estuary. Estuarine research focussed on the midestuary and the model domain was limited to the open water portion of the estuary. Two-dimensional hydrodynamic (RMA-2) and salinity (RMA-4) models were developed for this purpose (**Appendix H**). Since

1. FORTRAN is an abbreviation for Formula Translation Model

MFL issues focussed on the oligohaline zone, the model domain was expanded to include the riverine portion of the North Fork (**Appendix F**).

The hydrodynamic model has computer processing time and memory requirements that limit simulations to a few months. Therefore, the long-term watershed model results were scanned, a stereotypical MFL situation identified, and the hydrodynamic model simulated this shorter three-month period. Once the salinity behavior is known throughout a typical MFL period, the information can be used to convert a flow-frequency relationship into a salinity-frequency relationship that describes the likely extent and duration of oligohaline habitat.

The salinity model was used to locate the 5-ppt isohaline zone throughout the predevelopment MFL event. This was used to develop a salinity-frequency relationship for predevelopment conditions. The salinity-frequency relationship helped establish the minimal extent of the oligohaline zone under MFL conditions. The same methods were then reapplied using current (HSPF) hydrology. This established the minimal extent of the oligohaline zone under MFL conditions in today's watershed. Comparison of today's salinity-frequency relationship to the historical salinity-frequency relationship forms the basis of MFL recommendations.

Results of flow analyses for the North Fork, for historical and 1995 Base Case conditions, indicated that less water flowed to the North Fork under the 1995 Base Case than occurred under the NSM simulation. Further analysis indicated, however, that this reduction in flow occurred primarily during high flow periods and that, in fact, more water was being discharged from the North Fork to the estuary during low flow periods under the 1995 Base Case simulation than was discharged during similar periods under NSM simulation. Therefore, further analyses were conducted to characterize discharges to the estuary during very dry periods. Results of this analysis are discussed in **Chapter 5**.